PAAV Tabletop 4 Results – Integrating m:N Remotely Piloted Operations

February 8, 2023

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Agenda

- Tabletop need and purpose
- Participants and data collection method
- Summary of starting assumptions/training
- Scenario example
- Results – A selection of Challenges
- Results – A selection of Solutions
- Notional Operations Center
- Summary – m:N ratio considerations

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Tabletop Need

Current Trends in Air Traffic Operations:

- Increase in domestic U.S. passenger operations (4.8% per year) [1]
- Increase in domestic U.S. cargo operations (2.6% per year; 2022-42) [1]

Predicted Trends in Air Traffic Operations:

- Predicted demand for commercial passenger pilots will increase by 128,000 [2]
- Demand for **cargo** pilots should increase similarly

To be a seamless solution to meet market demands, uncrewed cargo operations should perform similarly to crewed aircraft, including following instrument flight rules (IFR) and conventional NAS structure and procedures. Operations should include turboprop aircraft like those that are typically used for current-day regional air cargo operations. These aircraft must be capable of flying into and out of airports that meet freight carriers' logistical needs, including regional airports and Class C and Class B airports.

Tabletop Purpose

To leverage SME feedback to identify barriers to *seamlessly* integrating uncrewed mid-sized cargo aircraft into the NAS and potential solutions to overcome those barriers. While previous tabletops[3] focused on potential impacts to air traffic controllers (ATCs) in the near-term evolution of uncrewed cargo operations, the current one concentrated on a further-term vision where more automation is leveraged and there is less centralized control. [4]

Automation Levels

Human > Shared > Supervisory > Automated > Fully Automated Control

Control Locus Levels

Centralized > Collaborative > Delegated > Distributed with Oversight > Fully Distributed

An m:N pilot-to-UA configuration was specifically investigated during this tabletop as a path towards the far-term vision for integrating autonomous cargo operations into the NAS.

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Participants

3 Commercial Pilots	Airline Transport Pilot (ATP), instrument and multi-engine ratings Combined 15,000 flight hours
3 Remote Pilots	Combined average of 7.66 years (combined 6,085 hours) civilian and military experience.
1 Dispatcher	Licensed with 43 total years of experience with Part 121 and 135 operations.
6 Air Traffic Controllers	Certified Professional Controllers with total years certified ranging from 9-34 years. All had experience at Air Route Traffic Control Center (ARTC), three had tower experience, five had Terminal Radar Approach Control (TRACON) experience, and four had en route experience.

Method

- Flexible Method for Cognitive Task Analysis (FLEX) method proposed by the United States Army as a knowledge elicitation technique for future concept. [5]
- With the FLEX method, subject matter experts are grouped by their type of expertise and interviewed sequentially, with each group building upon the comments and suggestions of the previous group.

Sessions

Session 1	5/16 – 5/19	6 Pilots & 1 Dispatcher
Session 2	5/24 – 5/26	6 ATCs
Session 3	5/27	All 13 SMEs

Structure

– Training: the problem space, activity expectations, and starting assumptions

– Pilots & Dispatcher Session – 3 ½ days of guided issue/solution discussions

– ATC Session – 2 ½ days of guided issue/solution discussions

- Discussion tailored to topics that may impact ATC
- Discuss solutions identified by Pilot & Dispatch that may impact ATC

– Combined Session – 1 day reviewing issues, proposed solutions and “m:N architectures”

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Assumptions – Far-Term Concept

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Possible **Far-Term** Assumptions (*in progress*)
Vehicle has **airworthiness certificate**, enabling commercial operations under 14 CFR
Vehicles are desired to be operated remotely with **multiple (m) operators per multiple (N) vehicles**, via more supervisory operator intervention
Vehicles are equipped with **advanced CA, DAA, and C2 capabilities**, including advanced terrain and weather avoidance capabilities
Contingency plans are dynamic with **well-defined automation and human roles**
UA will fly **IFR** and leverage **digital and/or visual-like flight rule** behavior where available
Penetration of these operations is expanded to **more complex airspace and major airports**
Airspace services are provided according to the **NAS 2035+ vision**, including, for example, more **automation** and **third-party services**
CNS may use advanced methods including more **digital communication between ATC and the ground station operator**, leveraging **satellite/cellular/HARS** technologies as feasible, and more advanced **vehicle-to-vehicle communications**
Operations will be enabled in **off-nominal conditions** such as lost link, inclement weather, and low visibility at airports.

Assumptions – UAS

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Doppler radar

- Provides wind shear alerts
- Provides display of significant convective activity

Flight Management System (FMS)

- Located at the GCS and on the UA to process and execute route and altitude requirements

Ground Proximity Warning System

Visual Technology

- Provides a means of detecting the runway environment during takeoff and landing
- Provides means to detect traffic, hazards, and obstacles during taxi
- Allows the RP to visually reference weather, other aircraft, or airborne hazards

Collision Avoidance System

- Resolution Advisories (RA)
- Detect and Avoid (DAA) system
  - Provides traffic with vector and altitude information on the GCS navigation display
  - Provides alerting and guidance resolutions

Surveillance Equipment

- ADS-B In/Out
- Air-to-Air Radar
- Transponder
  - 4096 Capable
  - Mode C
  - Mode S

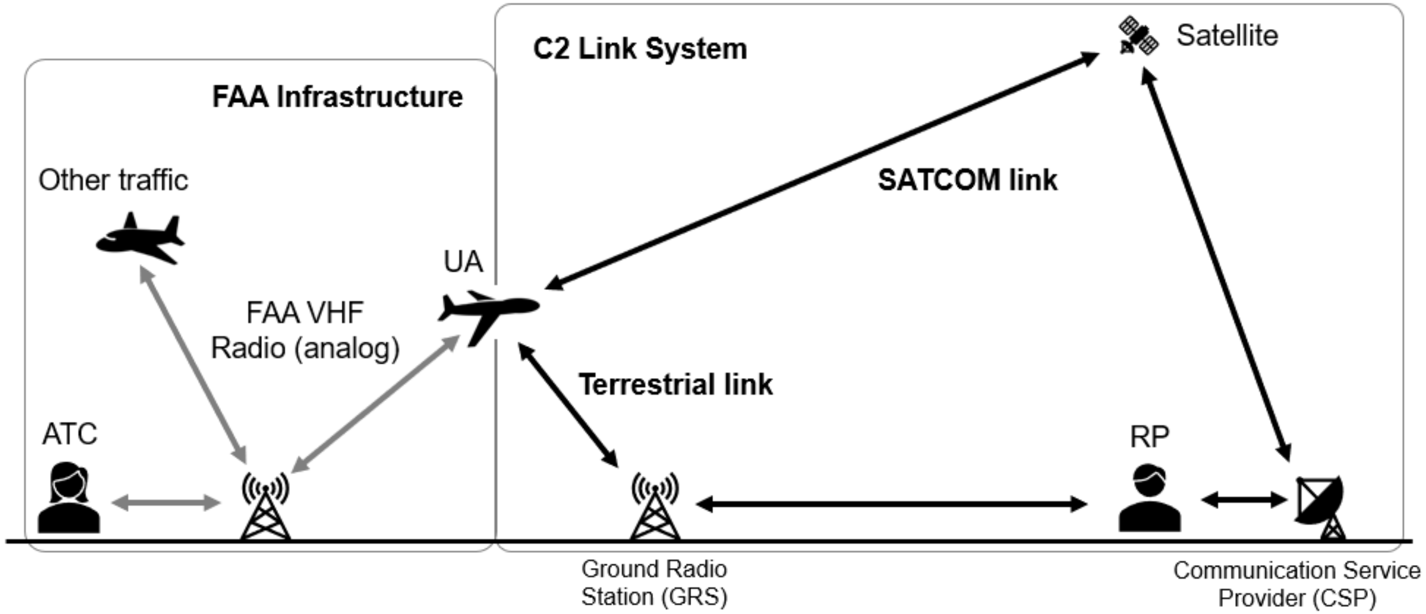
UA Assumptions

Specifications	Values
Endurance	3 hours
Speed	300 KTAS
Climb Rate	1850 fpm
Wingspan	80’ 7”
Weight	41,000 lbs. (max)
Service Ceiling	FL250

Assumptions – C2 Link

The C2 link has multiple purposes:

- The RP uses the link to command maneuvers of the UA (uplink)
- The UA uses the link to send state and subsystem telemetry data to the RP (downlink)
- The RP and ATC communicate via two-way voice and digital transmissions



- The UA and GCS send/receive surveillance data transmissions
- The UAS sends limited low-frame-rate video to the GCS for takeoff and landing. With future advancements, additional high-resolution data may also be transmitted through these links in other phases of flight

Assumptions – Scenarios

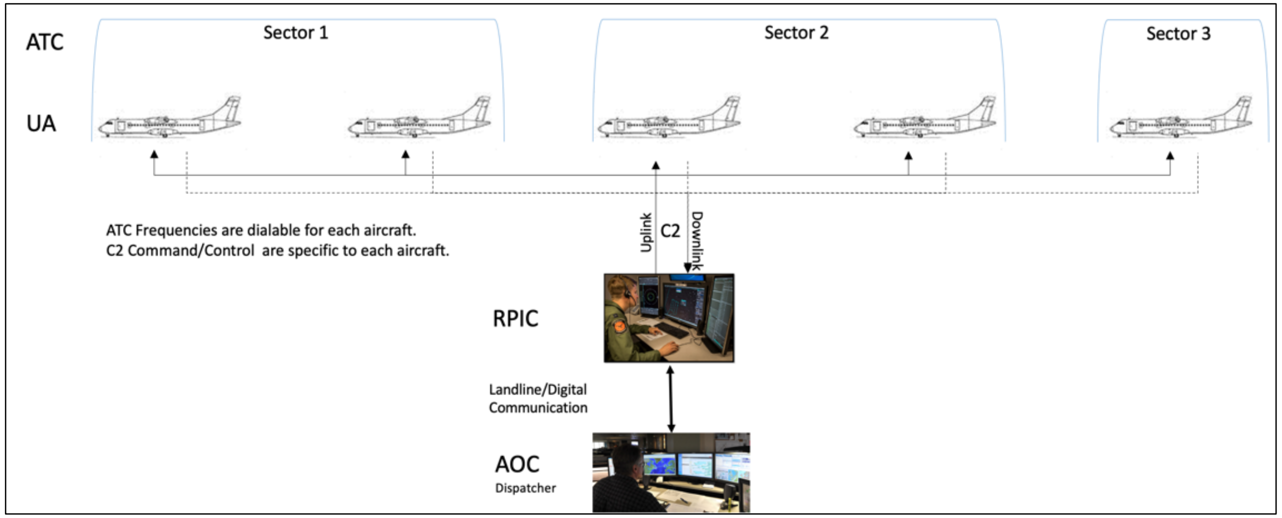
- **All Ownships are operated m:N (specifically 1:2+)**
- Regional Cargo Operations
- SATCOM and/or Terrestrial C2 Link available for the full flight
- Operations may or may not be in a similar location
- RPs are assigned by phase of flight (e.g., RP-Ground, RP-Terminal, RP-En route). Otherwise, roles and responsibilities were largely undefined.
- Ownships are capable of taxi without tow
- *Primary* communication is via voice
- Exact technologies were left purposefully ambiguous and vague

All scenarios were merely a **starting point** to the conversation.

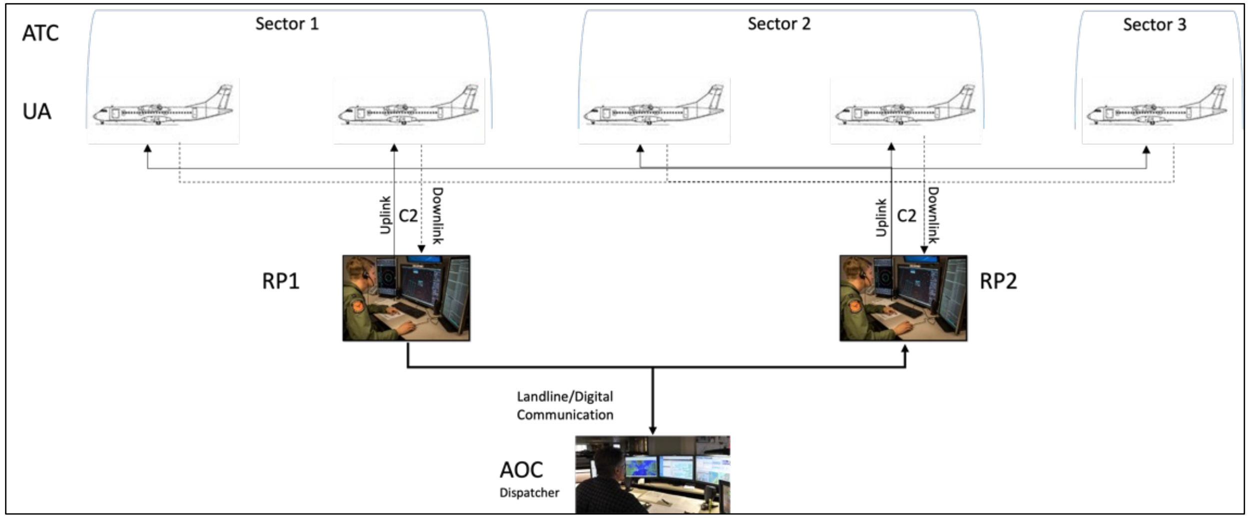
m:N Description

Multi-Vehicle Control (m:N) pilot-to-aircraft ratio

One or more operators (**m**) controlling multiple vehicles (**N**) at the same time



Hypothetical 1:5 RP to UA ratio



Hypothetical 2:5 RP to UA ratio

Participants were shown examples for multiple possible m:N configurations and were encouraged think beyond those examples to assess the optimal configuration for each scenario.

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Scenarios

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Phase of Flight	Scenario	Scenario Name
En Route	E1	Weather Avoidance
	E1a	LC2L During Weather Avoidance
	E2	DAA Alerting and Guidance
	E3	Mid-Flight Pilot Handoff
	E4	GCS Position Relief Briefing
	E5	Managing Multiple ATC Frequencies
	E6	Data Link Management
Approach	A1	Metering
	A1a	LC2L Descent to Landing
	A2	Holding
	A2a	LC2L while Holding
	A3	Sequencing (Sensor Spacing)
	A4	TRACON Resequencing
	A5	Missed Approach and Diversion
	A6	DAA Alerting and Guidance
	A7	Class D Pattern Entry
	A7a	LC2L Class D Pattern Entry
	A8	CTAF Operations
	A8a	LC2L CTAF Operations
Surface Operations	S1	Hold Short with Tower
	S2	Detailed Taxi Instructions and Following Traffic
	S3	LC2L During Taxi
Preflight	P1	Preflight
Departure	D1	Position and Wait and Ground Delay Program
	D2	Rejected Takeoff

- 25 unique scenarios
- Developed in collaboration with NASA SMEs
- Designed to investigate key concept areas:
  - Flight Route Planning
  - Separation and Flow Management
  - Traffic Pattern Integration
  - Contingency Management
  - Taxi, Takeoff, and Landing
  - Communication

Materials – Moderator Script

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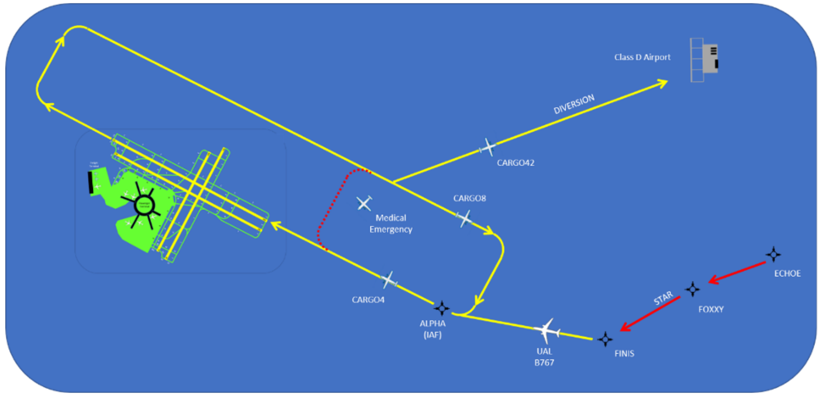
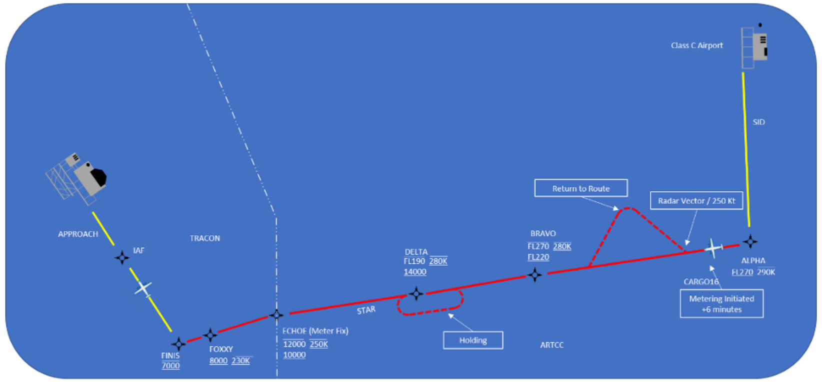
Phase of Flight: Approach

Overview (Slides 26, 27)

- This scenario involves several fixed wing twin turboprop aircraft performing regularly scheduled cargo operations in California.
- These flights are routine IFR operation arriving in the morning hours in marginal VMC.
- Weather at the Class B airport is marginal and variable due to fog.
- The flight is under the control of two RPICs during different phases of flight.
  - An RPIC-Terminal flying the UA within airspace controlled by a regional TRACON or local approach control associated with a Class B or Class C tower.
  - An RPIC-Enroute responsible for flying the UA within airspace controlled by an Air Route Traffic Control Center (ARTCC), or a UA arriving or departing from a Class D airport or Class E airport without an operating control tower.
- TRACON Operations
  - CARGO8
    - The flight has been given radar vectors for the left downwind and is on a final instrument approach at the Class B destination airport.
    - The RPIC-Terminal is on the pattern controller frequency.
    - The pattern controller is moderately busy sequencing aircraft to the airport.
  - CARGO4
    - The flight is given radar vectors for the left downwind for a final instrument approach at the Class B destination airport.
    - The RPIC-Terminal is on the pattern controller frequency.
    - The pattern controller is moderately busy sequencing aircraft to the airport.
  - CARGO42
    - The flight has made serval attempts to land, but visibility has not been sufficient.
    - In the event of a diversion, the UA will proceed to a nearby Class D airport.
    - The aircraft is being considered for diversion due to fuel constraints.
    - The RPIC-Terminal is on the local tower control frequency.
- Enroute Operations
  - CARGO16
    - The flight departs a Class C airport using an RNAV departure procedure that transitions to the STAR serving the Class B destination airport.
    - The RPIC-Enroute is on the Sector 5 frequency. Sector 5 is busy with sequencing and has a moderate workload.
- C2 links for communication and Command and Control are available for the end-to-end operations of Auto Cargo flights.





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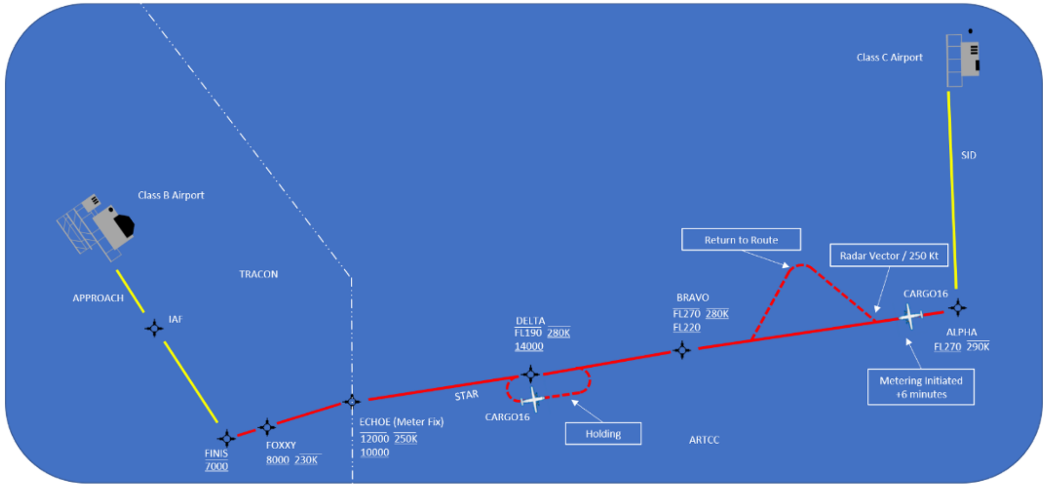
Topic A4: TMI – Metering (Slide 31)

- 20 NM from the transition point for the STAR, the enroute controller clears CARGO16 via the STAR for the destination airport and directs CARGO16 to comply with the restrictions on the STAR.
- The RPIC-Enroute reads back the clearance and configure CARGO16 to fly the STAR as cleared.
- 10 NM past the transition fix for the STAR, the Traffic Management Unit (TMU) determines that metering is required to balance the capacity and demand for the destination airport due to deteriorating visibility.
- Upon receiving notification that metering is in progress, the enroute controller turns on metering information on the ATC display and notes that CARGO16 will be required to absorb 6 minutes to meet its time at the meter fix. The controller determines that speed control and vectors will be required to meet the metering times over the meter fix.
- The enroute controller advises the RPIC-Enroute that metering is in progress and issues a speed restriction and a radar vector to CARGO16 for spacing.
- The RPIC-Enroute reads back the clearance, reduces CARGO16's speed, commands the UA to fly the assigned heading, and updates the contingency plan.
- The enroute controller monitors the progress of CARGO16, judges that the UA is now in conformance with the required time at the meter fix and turns the aircraft back to rejoin the STAR.
- The RPIC-enroute reads back the clearance and configures CARGO16 to rejoin the STAR.



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Materials – Moderator Questions

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	B	C	D
125	1 - Enroute	Topic E6: Data Link Managem	How does the use of a datalink-like system impact ATC operations? Could a datalink-like system's structure/design be compatible with current ATC or pilot procedures?
126	1 - Enroute	Topic E6: Data Link Managem	Could a datalink-like system's structure/design be compatible with current ATC or pilot procedures?
127	1 - Enroute	Topic E6: Data Link Managem	Assuming that today's data link implementation is very minimal, what type of improvements/enhancement would you expect to have 10 to 20 years down the road?
128	1 - Enroute	Topic E6: Data Link Managem	Anything else you'd like to discuss about this topic and m:N from your perspective? Any concerns?
129	2 - Approach	Topic A1: TMI - Metering	If the controller gives a time at a fix, can the pilot more easily manage several aircraft?
130	2 - Approach	Topic A1: TMI - Metering	ATC opinion of pilot response to: If the controller gives a time at a fix, can the pilot more easily manage several aircraft?
131	2 - Approach	Topic A1: TMI - Metering	Considering the other operations you'd be responsible for in this scenario (CARGO4, CARGO8, and CARGO42 all in TRACON, with CARGO42 making unsuccessful attempts to land)... Could you handle this situation if your other flights were nominal? Could you keep control of all of your original operations and perform all your aviate, navigate and communicate tasks **efficiently** and **effectively**?
132	2 - Approach	Topic A1: TMI - Metering	If not, what are the **barriers** that would keep you from handling all your flights satisfactorily? (low SA, high WL, decision making)
133	2 - Approach	Topic A1: TMI - Metering	If not, how/what would you **reallocate** to other resources? (Procedural: keep but hold, isolation by handoff of urgent op, handoff nominal ops, specialist RP, dispatch. Automation: (functions or tasks) Describe the pros and cons.
134	2 - Approach	Topic A1: TMI - Metering	When pilots stated that they may not be able to maintain m:N operations if all of their other operations were nominal but one was in *(insert situation/scenario)* , they suggested that *(insert procedural or technological solution)* could help maintain the safety and efficiency of the operations. Does this solution present any negative impact to your tasks or responsibilities as a controller?
135	2 - Approach	Topic A1: TMI - Metering	How would you modify this solution to be more acceptable from the controller's point of view? Is there an ATC-based solution that would be acceptable to resolve this instead?
136	2 - Approach	Topic A1: TMI - Metering	How would you make the **decision** about what to prioritize?
137	2 - Approach	Topic A1: TMI - Metering	If suggested, would the RP-RP **handoff** of a UA be based on pilot's workload, region or geographic position, specific situation? (e.g., holding, LC2L)
138	2 - Approach	Topic A1: TMI - Metering	Pilots suggested that the RP-RP handoff occur at *(insert suggested time/location)* . Do you agree that this is correct, or do you think that there might be a better time or location based off of your experience as a controller?
139	2 - Approach	Topic A1: TMI - Metering	Please explain the specific tasks or **functions** that would be kept or offloaded. (Information you'd want to receive differently for better SA, high WL tasks that could be streamlined with automation, human assistance from dispatch and/or an additional RP/operator)
140	2 - Approach	Topic A1: TMI - Metering	Pilots suggested that these *(insert tasks or functions)* be kept or offloaded during *(insert situation/scenario)* . Does this difference in task allocation present any negative impact to your tasks or responsibilities as a controller?
141	2 - Approach	Topic A1: TMI - Metering	Could you still handle this situation (m:N) if another flight required minor or moderate attention?

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Results – Operational Challenges

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Challenge Category	Challenge	Challenge Description
Flight Route Planning	Unclear R & Rs	m:N introduces ambiguity in who signs the release and who is legally in charge.
	Workload Limitations	Mitigating the added workload of completing preflight checklists.
Separation and Flow Management	Technology Limitations	DAA alerting system needs a design that that facilitates quick RP situation awareness and response. Also, false positive DAA alerts add to workload.
	Workload Limitations	Executing a hold and metering have a high cost for attentional resources and workload.
	Spacing	Weather avoidance may require more spacing.
Traffic Pattern Integration	Workload and SA Limitations	Terminal environment is an especially high workload space due to approach checklists, approach sequencing, missed approach vectoring, and ”visually” following other aircraft.
	Regulation Limitations	Desire to conduct VFR-like approaches (”visually” following an aircraft and calling the airport ”in sight”) while IFR; currently prohibited due to regulation.

Results – Operational Challenges

Challenge Category	Challenge	Challenge Description
Contingency Management	Workload and SA	Contingency planning (CP) can be a high workload task. LC2L requires higher communication with ATC. Need for UA behavior during LC2L to be predictable.
	Unclear Procedures	CP method varies depending on the event/environment; strong need to identify CP procedures to reflect unique preferred actions in each case
Taxi, Takeoff and Landing	Workload and SA	Maintaining adequate SA in ground and near-ground environments is difficult due to many factors, including owned aircraft located at different airports and the dynamic nature of this phase of flight. Checklists and monitoring multiple frequencies adds significant workload
	Technology Limitations	On board cameras lack necessary depth perception
Communication	Workload and SA	Attending to multiple frequencies is made difficult due to task switching and interruptions; Datalink may not be able to replace all verbal comms.

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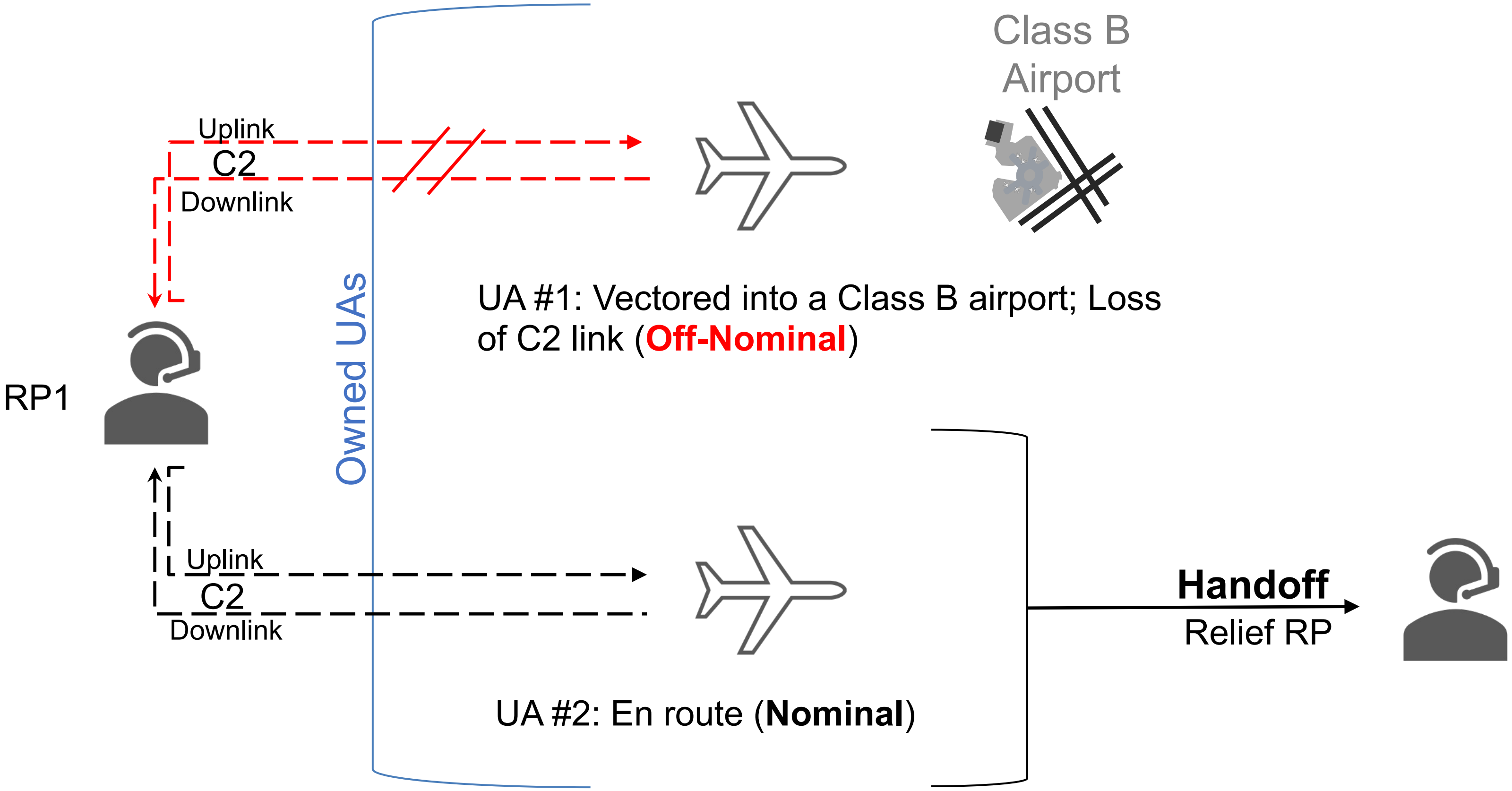
Results – Unplanned Handoff Example



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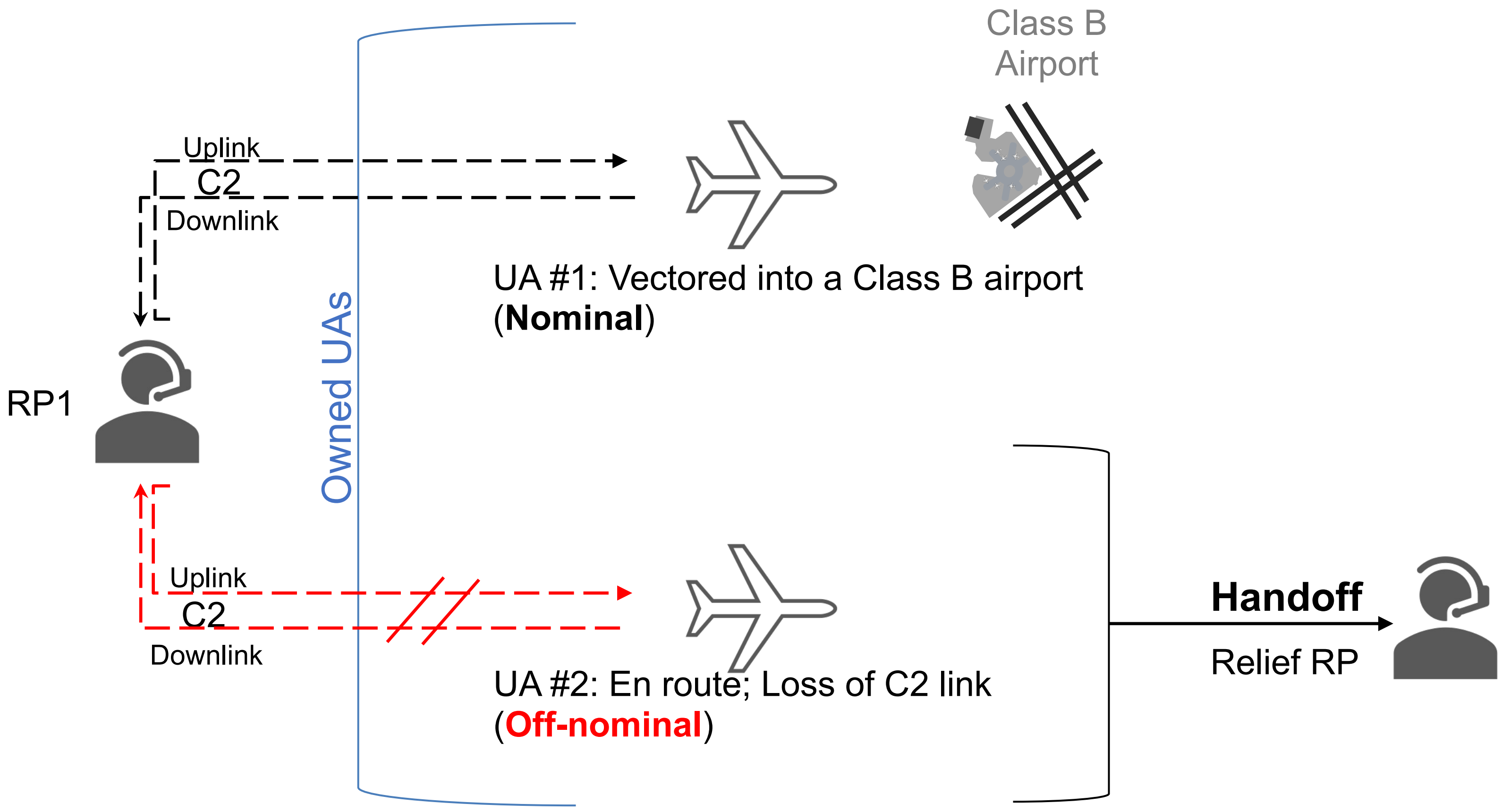

Results – Solutions (1 of 5)

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Solution Category	Solution	Solution Description
Technology	Automation for Maneuvering	• Feed re-routing information from UAs that are ahead and traveling on the same pre-canned travel path to automate vectoring (weather avoidance scenario) • Automation for resequencing: automate joining the downwind and integrating into a traffic pattern; single button click for executing clearance commands, UI capable of seamless switching between communication modes • Keep RP in the loop during automated events by employing automation-override capability coupled with displays which show automation's decision logic to keep sufficient awareness of their operation
	Automation for Communication	• Automation for clearance responses: software that "listens" to ATC radio transmissions • Software capable of identifying the called aircraft, generating appropriate confirmation or amended response, and allows a review of the response before sending to the controller
	Automation for Checklists	• Automate preflight, departure, and arrival checklists as much as possible*. For handoffs, pre-populate checklist items
	DAA	• Reduce number of clicks required for a DAA response by reducing the need to enter commands for specific headings or altitude • Software capable of automatically executing an RA maneuver if there were no RP response within a certain time frame following a DAA warning-level alert

Results – Solutions (2 of 5)

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Solution Category	Solution	Solution Description
Tools And User Interface	Environmental Situation Awareness Tools	• Tools capable of synthesizing finer weather details as well as both on-board and ground-based technologies for gathering weather data • Capability to overlay information that is pertinent to the operations on their displays including but not limited to weather data • Predictive software to anticipate non-planned handoffs that are based on assessing factors such as ATC traffic, weather, runway changes or closures
	Contingency Management Tools	• Employing a dynamic method to build contingency plans, utilizing drop-down menus to access pre-populated options for maximum efficiency • Preferred method of receiving clearances is to have digital clearances and have them be sent directly to the GCS
	Pilot Briefing Tools	• Move to digital briefing packages and flight books • Utilize messenger tools to allow quick communication with dispatch • A remarks section highlighting high level information dispatch wants RP to know • Correspond UA tail number to a QR code on the briefing package
	Checklist Tools	• Reduce input error and confusion between owned UA with separate screen for each UA • Have control station position relief briefings content information displayed and updated regularly and have read-and-reply checklist protocols, where there is affirmative confirmation requirement of each item during a shift change.

Results – Solutions (3 of 5)

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<table>
<tr><th>Solution Category</th><th>Solution</th><th>Solution Description</th></tr>
<tr><td rowspan="2">Best Practices And Recommended Procedures</td><td>Planned Handoffs</td><td>Handoff at predetermined points
Collocate the RPs in the same facility
Use verbal and visual handoff mode for confirmation positive transfer of UA control by an incoming RP (i.e., push to pass, shake to take).
Include contextual information for mid-flight handoff (flight parameters, any anomalies, airport information) and transcribe verbal handoffs
RP overlap: Turning the controls over to the incoming pilot before the transfer of full responsibility when conducting GCS position relief briefings
Assign UA that are regionally close to each other to contain all owned UA to a single map</td></tr>
<tr><td>Non-Planned Handoffs</td><td>Workload-based handoff decisions: General rule of thumb is to keep off-nominal UA and handoff the nominal due to the time it takes to transfer off-nominal SA
Geographically-based handoff decision: Handoff the UA to someone who recently completed the same task/problem in the same geographical area (i.e., rerouting around a developing weather cell) in the case of sudden need to load-shed
Have several pilots on standby and ready to receive handoffs in order to accommodate a sudden need to load-shed</td></tr>
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Results – Solutions (4 of 5)

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Solution Category	Solution	Solution Description
Best Practices And Recommended Procedures (continued)	Building a Contingency Plan	• Include flexibility to respond with canned amendments to uploaded contingency plans • Update the contingency plan first or at the same time as updating an operational plan • If multiple UA regain C2 link simultaneously, deconflict expect further clearance times so that the LC2L UA do not attempt to execute the Standard Terminal Arrival (STAR) at the same time CP Solutions for specific airspace/situations: • CP for LC2L in the terminal environment should be unique to each individual airport and developed with TRACON and/or tower controllers' involvement • CP solution options for LC2L during a traffic pattern entry included holding, auto-land, or executing a missed approach; Controllers agreed that published missed approach would be safer than utilizing auto-land LC2L logic • CP solution for LC2L while on a missed approach in the CTAF environment was to go-around and re-enter the traffic pattern as part of a standard operating procedure • CP solution for LC2L during the descent phase of flight in a Class B environment was to route the UA to alternate airports (i.e., Class D airports) • CP solution for LC2L while taxiing is to have the UA come to a stop rather than auto-taxi back to the gate

Results – Solutions (5 of 5)

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Solution Category	Solution	Solution Description
Best Practices And Recommended Procedure (continued)	Separation and Flow Management	• Give more space around developing weather—25 nautical mile buffer • In CTAF environment, extended downwind leg could allow more time to state UA intentions with nearby traffic on the CTAF and could also mitigate speed differences with slower aircraft • Current day metering (follow vectors for path stretching) without automation or data link, is plausible in m:N operations. However, automation technology with supporting auto-land functionality, specifically for the ILS Category III approaches, could be expanded
Communication	Datalink	• Datalink preferred for non-immediate ATC communication, and voice mode for immediate ATC instructions, such as descend or climb instruction or traffic alerts • Datalink UI: collocating data link messages with a map, having a dedicated data link display, and/or color-coding messages to the owned UA to match a color within a corresponding data link window • Leverage ground-based fiber optic technology to relay messages to and from the GCS rather than through the UA to reduce delay and increase robustness
	Radio	• Automate clearance readbacks with opportunity to review • Prioritize maneuvering clearances over advisories when there are multiple clearances at the same time as part of a standard operating procedure • UI: include a single and automatically populated push button for frequency transfers and a dedicated dial to switch between different owned UA

Results – Roles and Responsibilities

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New or Amended Roles for m:N Operations	
Dispatch	• Additional responsibilities: be active in pilot load-shedding, such as for a diversion or weather delays, and identifying candidate handoff points prior to an event or when delays are known • Leverage dispatchers and their tools to allow for more time for contingency planning
Information Support Personnel	• Make another dispatcher or a dedicated personnel available during RP briefings for the RP to query for updates or general questions before gaining the next UA; especially critical when there are multiple RPs downstream for a single UA
Remote Pilot	• Give all RPs a flight plan and briefing at the start of the shift but assume legal responsibility after the incoming RP gives a verbal and a visual confirmation of positive control during midflight handoff; seat swaps were also considered acceptable if collocated
Ground Crew	• When Ground (Terminal) RP is off site, the legal responsibility for performing a proper aircraft pre-flight “walkaround” will shift to ground crew • Additional ground crew roles for potential taxiing, pushback and off-nominal recovery tasks
Communication Personnel	• Dedicated staff at the GSC to monitor communications via radio (if data link is not yet fully integrated or efficient)

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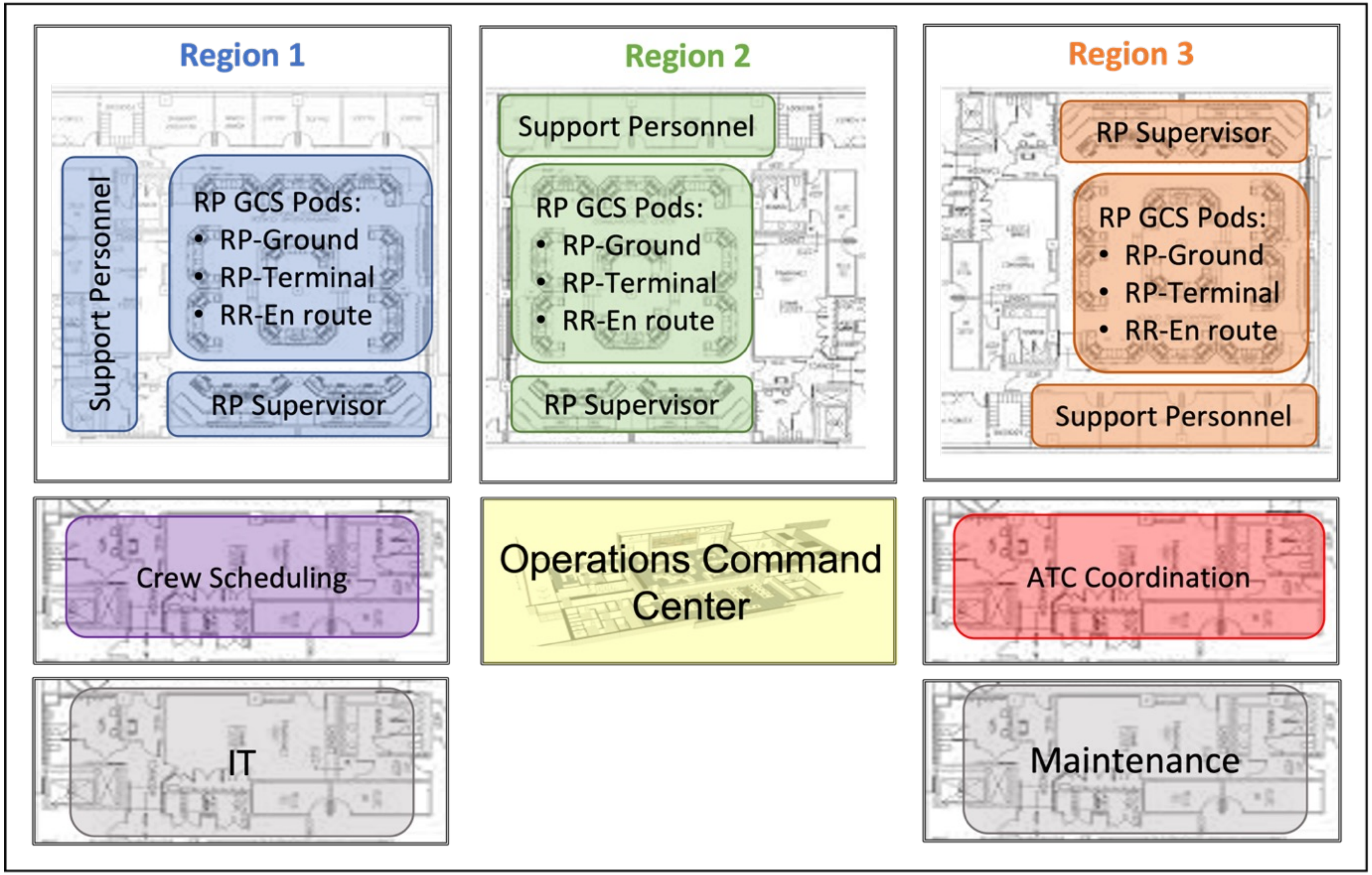
Notional m:N Operations Center



Agenda

- Tabletop need and purpose
- Participants and data collection method
- Summary of starting assumptions/training
- Scenario example
- Results – A selection of Challenges
- Results – A selection of Solutions
- Notional Operations Center
- Summary – m:N ratio considerations

m:N Ratio Considerations

National Aeronautics and Space Administration

Determining exact m:N ratios for future operations was outside the scope of Tabletop Four; however, key factors were identified that may impact the resulting ratios. Listed below are a selection of conditions that participants repeatedly circled back to as variables that would likely impact the viability of m:N operations:

- Airspace complexity (i.e., airspace class, traffic density and flow, types of other nearby operations, others' familiarity with UA operations, weather, arrival and departure routes, ATC vectoring or holdings).
- The amount of interaction the airspace requires of the UA and therefore the attention of the RP.
- Presence or absence of RP support personnel.
- Maturity of RP supporting UI design and technologies, including automation.
- Presence or absence of clear and appropriate procedures for seamless transfer of a UA from one RP to another.
- Level of training for RPs, ATC, ground crews, dispatchers, etc.
- Level of ATC & carrier pre-coordination on best practices in case of non-nominal events.
- Communication architecture: radio-only, data link-only, or a combination of both.
- Presence or absence of best practices to segment flights for RPs (versus a series of end-to-end flights) that operate in similar geographical areas.
- Presence or absence of flight schedules designed to minimize high workload situations for m:N-operated flights.

Questions

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